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TEST RESULTS - HEMISPHERICAL SPECIMENS SUPPLEMENT II TO HELMET DESIGN CRITERIA FOR IMPROVED CRASH SURVIVAL

By

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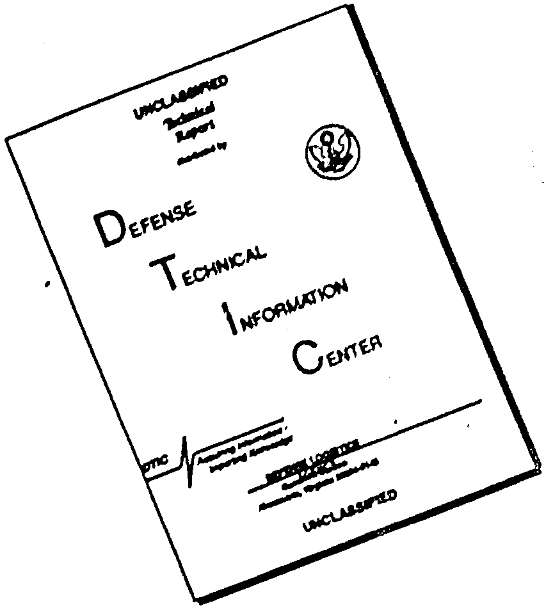

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to
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for

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FOREWORD

This supplement on the results of impact tests on 27 different types of helmet construction is separated from the basic report in order that readers interested only in this subject can review the detailed data independently of the basic report.

ILLUSTRATIONS

TABLES

SUPPLEMENT II
TEST RESULTS - HEMISPHERICAL SPECIMENS

The results of the 27 tests conducted on the hemispherical specimens are presented in Tables 1 and 2 and in Figures 2 through 9. Table 1 lists the materials used in each specimen as well as the total weight of each. Table 2 lists the acceleration onset rate, maximum (peak) acceleration, rebound height, and deformation in the simulated scalp. The simulated scalp of 0.25-inch thickness was described under Description of Test Specimens.* Not all of the data recorded in the tests are presented in Table 2 since some of the specimens were impacted from 8- and 10-foot heights, in which case none of the specimens were capable of preventing excessive acceleration values. The acceleration-time curves for the most interesting specimens are presented in Figures 2 through 9. The acceleration-time curves are direct copies of the data as photographed by the Polaroid camera from the oscilloscope.

A review of the data presented in Tables 1 and 2 reveals the following results:

1. The specimens with 0.07- to 0.125-inch magnesium and aluminum outer shells (specimens 4, 5, and 8) gave peak accelerations of 125 to 140G for the 4-foot, 90-degree-corner impactor drops. This is in excess of the value desired as shown in the section on Head Acceleration Limits.** Shells of 0.04- to 0.05-inch thickness (specimens 6, 7, 16, 18, and 20) of proper energy-absorbing material density will perform better than the thicker shell specimens up to a drop height of 4 feet (16-feet-per-second-velocity impact). A review of the maximum velocity impact possible at a 100G acceleration level in the main report (reference Figure 1) indicates 16 to 18 feet per second; therefore, the results correlate very well with the theoretical predictions.

2. The relatively thin ABS, nylon, and fiber glass outer shell specimens (9, 10, 11, and 12) did not perform as well as the thicker nylon and fiber glass shells (such as 14 and 15). The extremely light shells do not distribute the load from a 90-degree-corner impact over a sufficient area; thus less energy is absorbed, since a lesser area of liner is crushed.

*See basic report, Helmet Design Criteria for Improved Crash Survival, page 33.

**See basic report, page 10.

TABLE 1. HEMISPHERICAL TEST SPECIMEN MATERIALS

Spec. No.	Outer Shell Material	Outer Shell Thickness (in.)	Energy-Absorbing Material	Energy-Absorbing Mat. Density (lb/ft^3)	Inner Shell Material	Total Weight (lb)	Inner Liner Material
4.	AZ-31B Magnesium (partially annealed)	0.125	5052 Alum. Flexcore (0.33 in. Cells - 0.0013 in. thick)	2.2	2-Ply Fiber glass	1.06	Ensolite Type AH
5.	" " "	0.090				0.88	
6.	" " "	0.050				0.55	
7.	2024-T42 Alum. (heat treated)	0.050				0.82	
8.	" " "	0.070				1.02	
9.	Acrylonitrile Butadiene-Styrene (ABS)	0.05	5052 Alum. Flexcore	2.2		0.55	
10.	Nylon-Epoxy 4-Ply	0.06	Polyurethane Foam	4.0		0.52	
11.	Fiber glass-Epoxy 4-Ply	0.04	" "	4.0		0.60	
12.	Nylon-Epoxy 4-Ply	0.06	5052 Alum. Flexcore	2.2		0.55	
13.	Nylon-Epoxy 4-Ply and Alum. Hexagon Plates*	0.13	" " "	2.2		0.97	
14.	Fiber glass-Epoxy 8-Ply	0.08	Polyurethane Foam	4.8		0.88	
15.	Nylon-Epoxy 8-Ply	0.10		4.0		0.71	
16.	2024-T42 Alum. (heat treated)	0.050		5.0	2-Ply Fiber glass	0.79	
17.	Fiber glass-Epoxy 8-Ply	0.08	Polyurethane Foam	4.0	NONE	0.57	
18.	AZ-31B Magnesium (annealed)	0.040	5052 Alum. Flexcore	2.2	3-Ply Fiber glass	0.58	

18.	AZ-31B Magnesium (annealed)	0.040	5052 Alum. Flexcore	2.2	3-Ply Fiber glass	0.58	
19.	" " "	0.025	" " "	2.2		0.48	
20.	2024-0 Aluminum (annealed)	0.040	5052 Alum. Flexcore	2.2		0.63	
21.	AZ-31B Magnesium (annealed)	0.040	Polyurethane Foam	6.0		0.64	
22.	" " "	0.025		6.0		0.53	
23.	2024-0 Aluminum (annealed)	0.040	Polyurethane Foam	7.0		0.64	
24.	AZ-31B Magnesium (annealed)	0.040	B. F. Goodrich-H334 Polyvinyl Chloride Foam	3.2		0.62	
25.	" " "	0.025		3.2		0.52	
26.	Nylon-Epoxy 8-Ply	0.12	B. F. Goodrich-H334 Polyvinyl Chloride Foam	3.2		0.81	
27.	ABS	0.08	Polyurethane Foam	3.7		0.54	
28.	Polycarbonate	0.07	Polyurethane Foam	3.1	3-Ply Fiber glass	0.61	
29.	ABS	0.10	ABS Foam	11.0 Approx.	0.80 ABS	0.81	Ensolite Type AH
30.	Royalite Sandwich	0.44	Goodrich H-334 (0.31 in. thick)	3.2	NONE	0.67	Ethafoam

* The 7075-T6, 1.25 hexagon plates of 0.053 thickness were inlaid between 4 plies of nylon cloth as shown in Figure 1.

TABLE 2. TEST RESULTS OF HEMISPHERICAL SPECIMENS

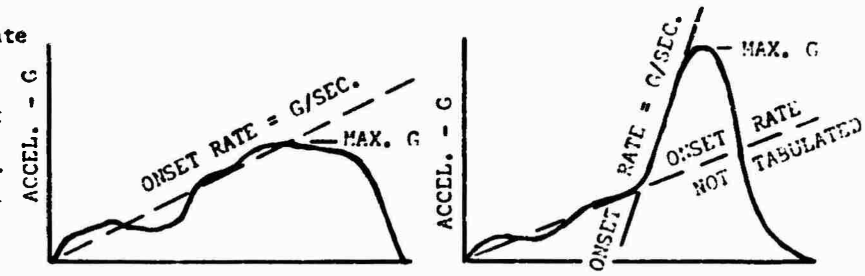
(Impactor Weight = 13.5 pounds, Total Material Thickness = 1.0 inch)

Notes:

1. See Table 2, basic report, Helmet Design Criteria for Improved Crash Survival, for description of specimens.
2. The values in this table are based upon acceleration-time traces which fit the general shape of one of the traces shown in the sketch below:

The tabulated onset rate is the greater of the rates shown in traces A, B. The high onset rates are associated with the permanent depressions in the skull cap.

3. When blanks occur in the tabulation, no drop was made in this condition.



TIME - SEC. TRACE A

TIME - SEC. TRACE B

IMPACTORS → Specimen Identity ↓		90-Degree Cone (0.06-In. Radius) 2 ft	3 ft	4 ft	90-Degree Corner (0.25-In. Radius) 4 ft	5 ft	6 ft	Flat (4.5-In. Diameter) 5 ft	6 ft
4	Onset rate(G/sec)	-	-	-	100,000	-	120,000	-	-
	Max Accel.(G)	-	-	-	140	-	[illegible]	-	-
	Rebound Ht.(ft)	-	-	-	0.2'	-	0.3'	-	-
	Footnotes	-	-	-	-	-	-	-	-
5	Onset rate	-	-	-	35,000	-	45,000	-	-
	Max Accel.	-	-	-	125	-	160	-	-
	Rebound Ht.	-	-	-	0.3'	-	0.3'	-	-
	Footnotes	-	-	-	-	-	-	-	-
6	Onset Rate	-	-	-	20,000	-	125,000	-	-
	Max Accel.	-	-	-	100	-	220	-	-
	Rebound Ht.	-	-	-	0.3'	-	0.5'	-	-
	Footnotes	-	-	-	-	-	-	-	-
7	Onset rate	-	-	30,000	25,000	-	25,000	-	-
	Max Accel.	-	-	120	110	-	150	-	-
	Rebound Ht.	-	-	0.3'	0.3'	-	0.5'	-	-
	Footnotes	-	-	a	-	-	-	-	-
8	Onset rate	-	7,000	14,000	30,000	-	-	-	100,000
	Max Accel.	-	50	80	140	-	170	-	280
	Rebound Ht.	-	0.3'	0.3'	0.4'	-	0.5'	-	-
	Footnotes	-	-	-	-	-	-	-	-
9	Onset rate	-	-	-	125,000	190,000	-	-	-
	Max Accel.	-	-	-	190	300	-	-	-
	Rebound Ht.	-	-	-	0.3'	0.5'	-	-	-
	Footnotes	-	-	-	-	b	-	-	-
10	Onset rate	-	-	70,000	125,000	165,000	180,000	-	30,000
	Max Accel.	-	-	195	190	270	325	-	160
	Rebound Ht.	-	-	0.4'	0.6'	0.7'	0.8'	-	0.8'
	Footnotes	-	-	c	d	b	c	-	-
11	Onset rate	-	-	80,000	95,000	125,000	190,000	-	40,000
	Max Accel.	-	-	180	185	250	295	-	180
	Rebound Ht.	-	-	0.4'	0.6'	0.7'	0.8'	-	0.8'
	Footnotes	-	-	c	d	-	c	-	-

TABLE 2. TEST RESULTS OF HEMISPHERICAL SPECIMENS (CONT'D.)

12	Onset rate	-	-	50,000	95,000	120,000	240,000	-	35,000
	Max Accel.	-	-	160	170	200	300	-	180
	Rebound Ht.	-	-	0.4'	0.5'	0.7'	0.7'	-	0.7'
	Footnotes	-	-	c	d	-	c	-	a
13	Onset rate	-	-	25,000	16,000	25,000	35,000	-	35,000
	Max Accel.	-	-	120	100	130	165	-	180
	Rebound Ht.	-	-	0.3'	0.4'	0.6'	0.7'	-	0.8'
	Footnotes	-	-	b	d	b,d	c	-	c
14	Onset rate	-	-	30,000	22,000	23,000	25,000	36,000	40,000
	Max Accel.	-	-	105	100	115	140	185	185
	Rebound Ht.	-	-	0.4'	0.5'	0.5'	0.7'	0.7'	0.7'
	Footnotes	-	-	-	d	-	a	-	-
15	Onset rate	-	-	55,000	12,000	26,000	36,000	26,000	-
	Max Accel.	-	-	150	95	130	160	135	-
	Rebound Ht.	-	-	0.5'	0.5'	0.5'	0.7'	0.5'	-
	Footnotes	-	-	-	d	b,d	c	b***	-
16	*Onset rate	-	-	8,000	18,000	21,000	22,000	-	-
	Max Accel.	-	-	80	110	120	125**	-	-
	Rebound Ht.	-	-	0.4'	0.3'	0.4'	0.5'	-	-
	Footnotes	-	-	-	-	-	d	-	-
17	Onset rate	5,000	-	-	26,000	32,000	70,000	60,000	-
	Max Accel.	55	-	-	120	160	235	200	-
	Rebound Ht.	0.3'	-	-	0.5'	0.8'	0.9'	0.9'	-
	Footnotes	a	-	-	b,d	c	c	-	-
18	Onset rate	16,000	-	-	8,000	48,000	112,000	50,000	58,000
	Max Accel.	65	-	-	100	160	225	160	180
	Rebound Ht.	0.2'	-	-	0.3'	0.4'	0.4'	0.3'	0.4'
	Footnotes	-	-	-	d	-	b	-	-
19	Onset rate	25,000	-	-	35,000	60,000	-	30,000	50,000
	Max Accel.	100	-	-	135	170	-	150	200
	Rebound Ht.	0.2'	-	-	0.3'	0.4'	-	0.3'	0.4'
	Footnotes	b	-	-	a	a	-	-	-
20	Onset rate	10,000	34,000	-	13,000	42,000	54,000	58,000	58,000
	Max Accel.	65	125	-	105	165	190	145	160
	Rebound Ht.	0.2'	0.3'	-	0.4'	0.5'	0.5'	0.4'	0.5'
	Footnotes	-	b	-	d	a,d	a,d	-	-
21	Onset rate	8,000	18,000	-	26,000	50,000	86,000	91,000	107,000
	Max Accel.	55	95	-	135	175	240	230	265
	Rebound Ht.	0.2'	0.3'	-	0.4'	0.5'	0.6'	0.5'	0.6'
	Footnotes	-	b	-	d	-	a	-	-
22	Onset rate	10,000	50,000	-	55,000	120,000	-	50,000	65,000
	Max Accel.	65	155	-	180	205	260	200	245
	Rebound Ht.	0.2'	0.3'	-	0.4'	0.6'	0.7'	0.4'	0.6'
	Footnotes	b	c	-	-	-	a	-	-

* Total Specimen Thickness 1.25 in.

** This low acceleration level is probably due to the extra thickness of energy-absorbing foam in this specimen.

*** 90-Degree-Corner Impactor used instead of flat impactor.

TABLE 2. TEST RESULTS OF HEMISPHERICAL SPECIMENS (CONT'D.)

23	Onset rate	11,000	13,000	-	22,000	45,000	65,000	99,000	99,000
	Max Accel.	60	85	-	120	160	220	245	275
	Rebound Ht.	0.2'	0.3'	-	0.4'	0.5'	0.7'	0.5'	0.8'
	Footnotes	-	b	-	d	-	-	-	-
24	Onset rate	13,000	-	-	57,000	128,000	200,000	26,000	200,000
	Max Accel.	90	-	-	180	270	385	175	330
	Rebound Ht.	0.3'	-	-	0.4'	0.5'	0.7'	0.8'	1.0'
	Footnotes	b	-	-	a,d	b	c	-	-
25	Onset rate	500,000	-	-	110,000	200,000	260,000	95,000	330,000
	Max Accel.	210	-	-	220	350	440	245	390
	Rebound Ht.	0.2'	-	-	0.3'	0.5'	0.7'	0.8'	1.2'
	Footnotes	c	-	-	a	c	c	-	-
26	Onset rate	8,000	-	-	51,000	190,000	200,000	180,000	300,000
	Max Accel.	55	-	-	150	255	360	240	375
	Rebound Ht.	0.3'	-	-	0.7'	0.9'	1.1'	0.9'	1.3'
	Footnotes	a	-	-	a	b	c	-	-
27	Onset rate	11,000	-	-	95,000	-	220,000	100,000	400,000
	Max Accel.	55	-	-	200	-	390	245	440
	Rebound Ht.	0.3'	-	-	0.4'	-	0.6'	0.8'	1.0'
	Footnotes	b	-	-	a	-	c	-	a
28	Onset rate	11,000	-	-	175,000	200,000	-	85,000	170,000
	Max Accel.	85	-	-	240	350	-	220	335
	Rebound Ht.	0.3'	-	-	0.6'	0.7'	-	0.9'	1.1'
	Footnotes	c	-	-	a	a	-	-	a
29	Onset rate	12,000	-	-	105,000	200,000	200,000	100,000	165,000
	Max Accel.	75	-	-	240	320	365	260	345
	Rebound Ht.	0.3'	-	-	0.4'	0.5'	0.7'	0.7'	0.8'
	Footnotes	b	-	-	-	-	-	-	-
30	Onset rate	10,000	-	-	125,000	180,000	210,000	105,000	295,000
	Max Accel.	60	-	-	245	320	375	275	390
	Rebound Ht.	0.3'	-	-	0.3'	0.4'	0.6'	0.7'	0.8'
	Footnotes	c	-	-	-	-	-	-	-

Notes

a - Slight permanent depression of 0.04-inch depth and 0.3-inch-square area or less in simulated scalp.

b - Moderate permanent depression of 0.04- to 0.10-inch depth and up to 0.8-inch-square area or more in simulated scalp.

c - Severe permanent depression of 0.10-inch depth and 0.8-inch-square area or more in simulated scalp.

d - Average reading of 2 drops.

3. Specimen 13 (reference Figure 1) with the inlaid metal plates provided good load distribution to the flexcore liner for all three types of impactors; however, the weight of this specimen was about one-third more than specimen 20, which performed almost as well for all three impact surfaces.

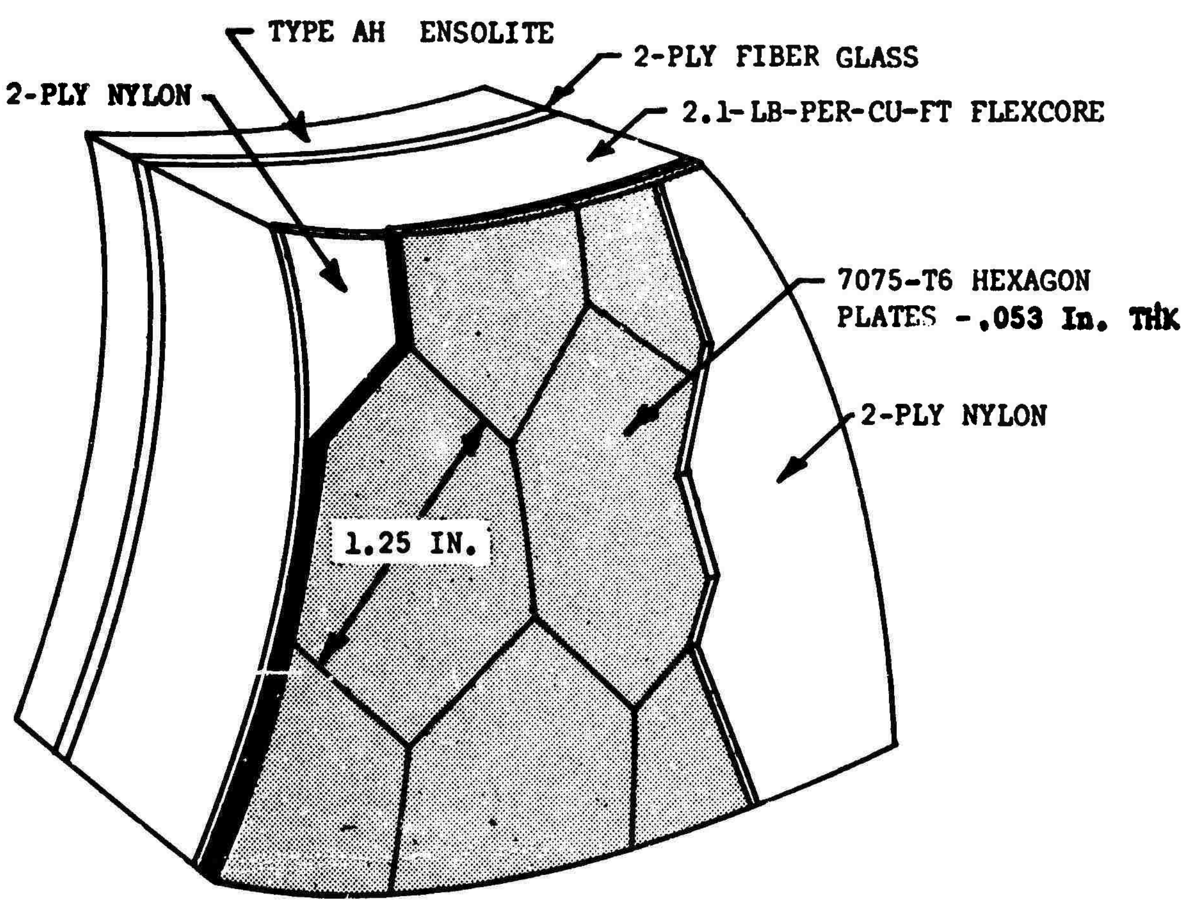
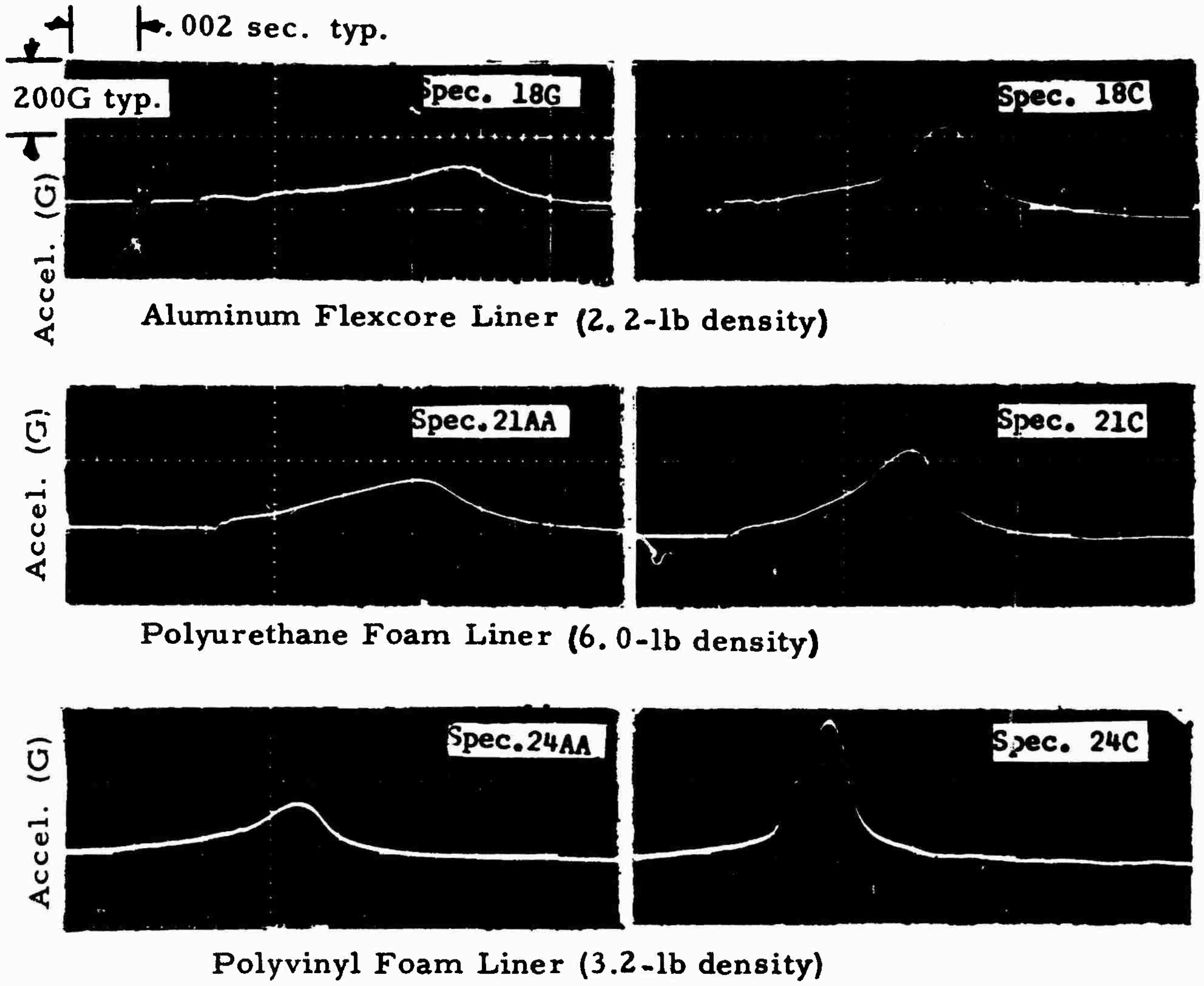


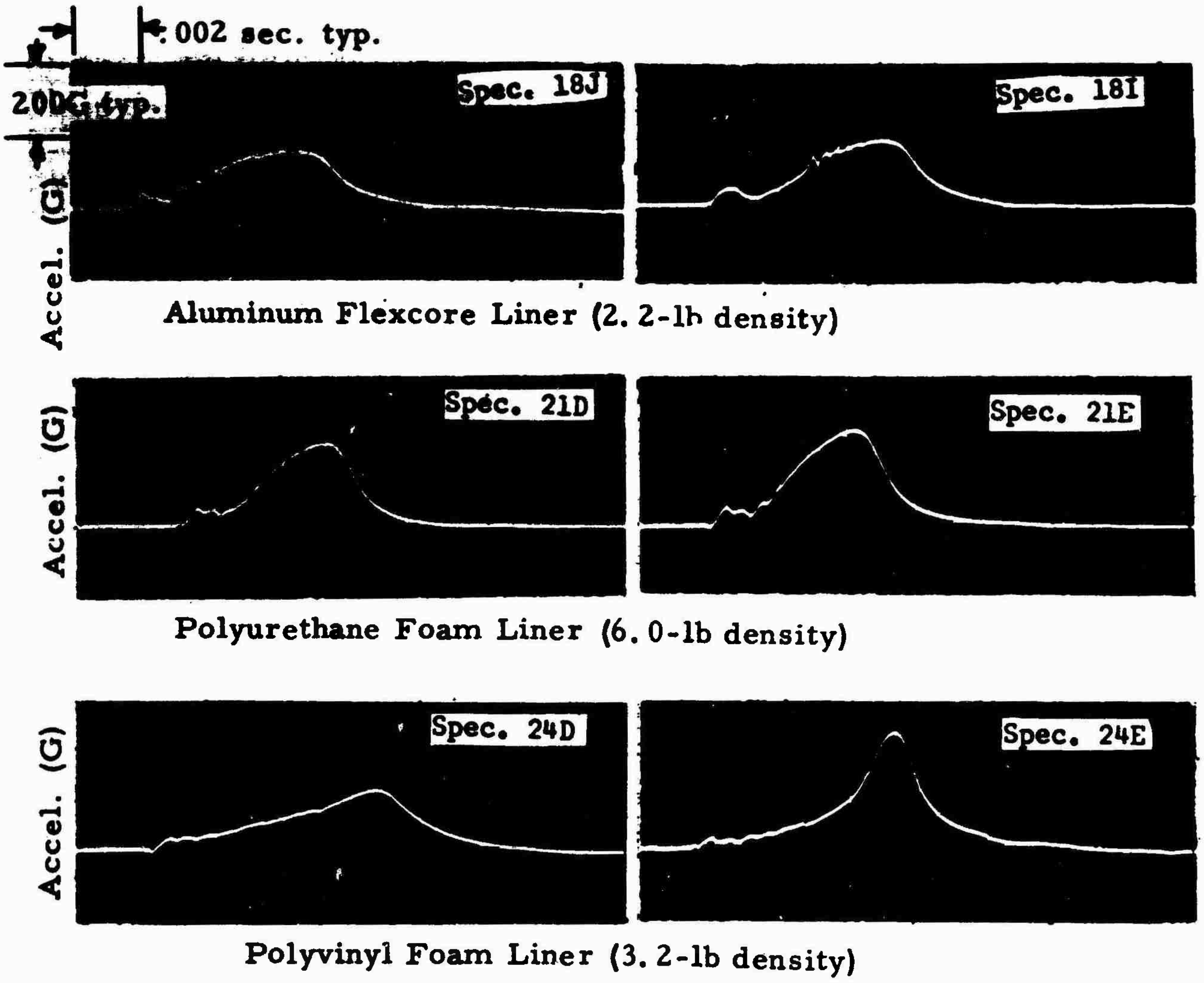
Figure 1. Construction Detail of Specimen 13.



DROP HEIGHT - 4 FEET   DROP HEIGHT - 6 FEET

90-DEGREE-CORNER IMPACTOR

Figure 2. Acceleration-Time Data-0.04 Annealed Magnesium Outer Shell.



DROP HEIGHT - 5 FEET

DROP HEIGHT - 6 FEET

FLAT IMPACTOR

Figure 3. Acceleration-Time Data-0.04 Annealed Magnesium Outer Shell.

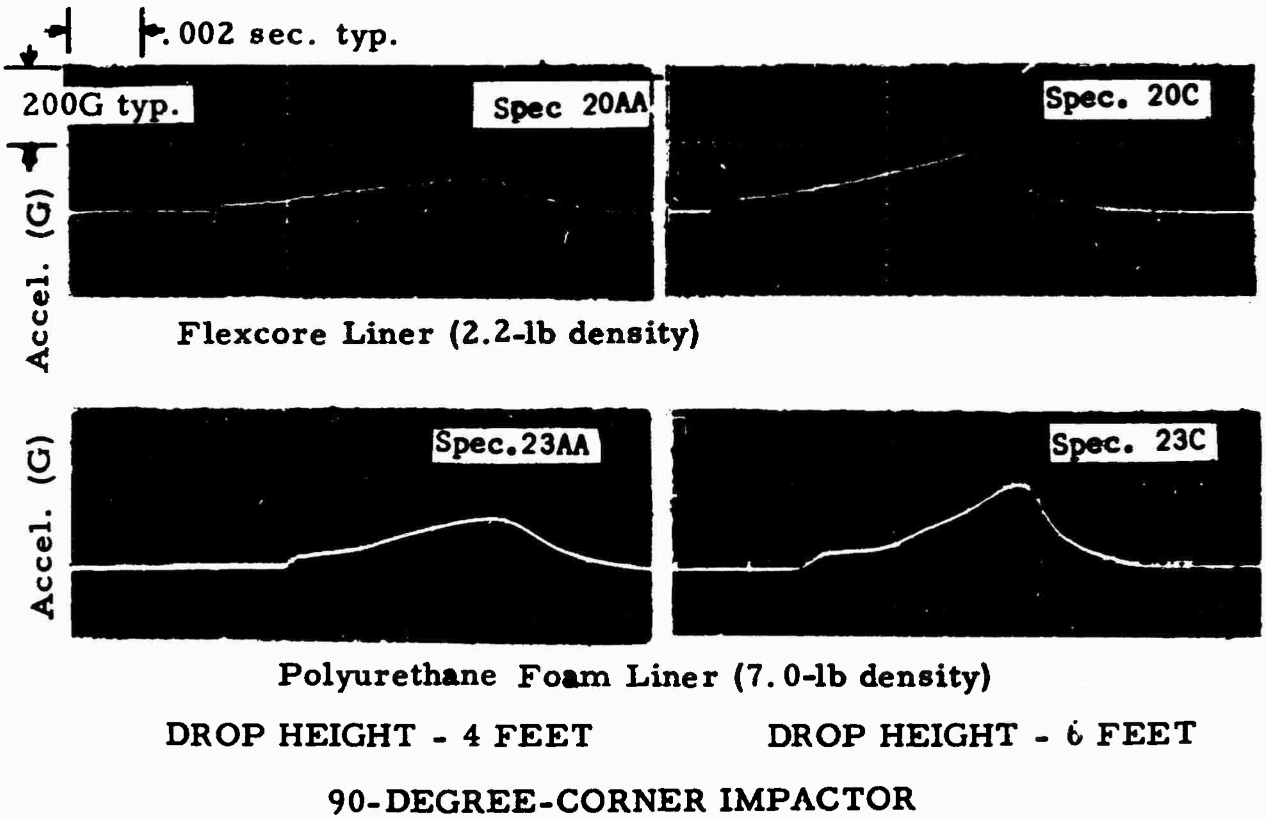


Figure 4. Acceleration-Time Data- 0.04 Annealed Aluminum 2024-0 Outer Shell.

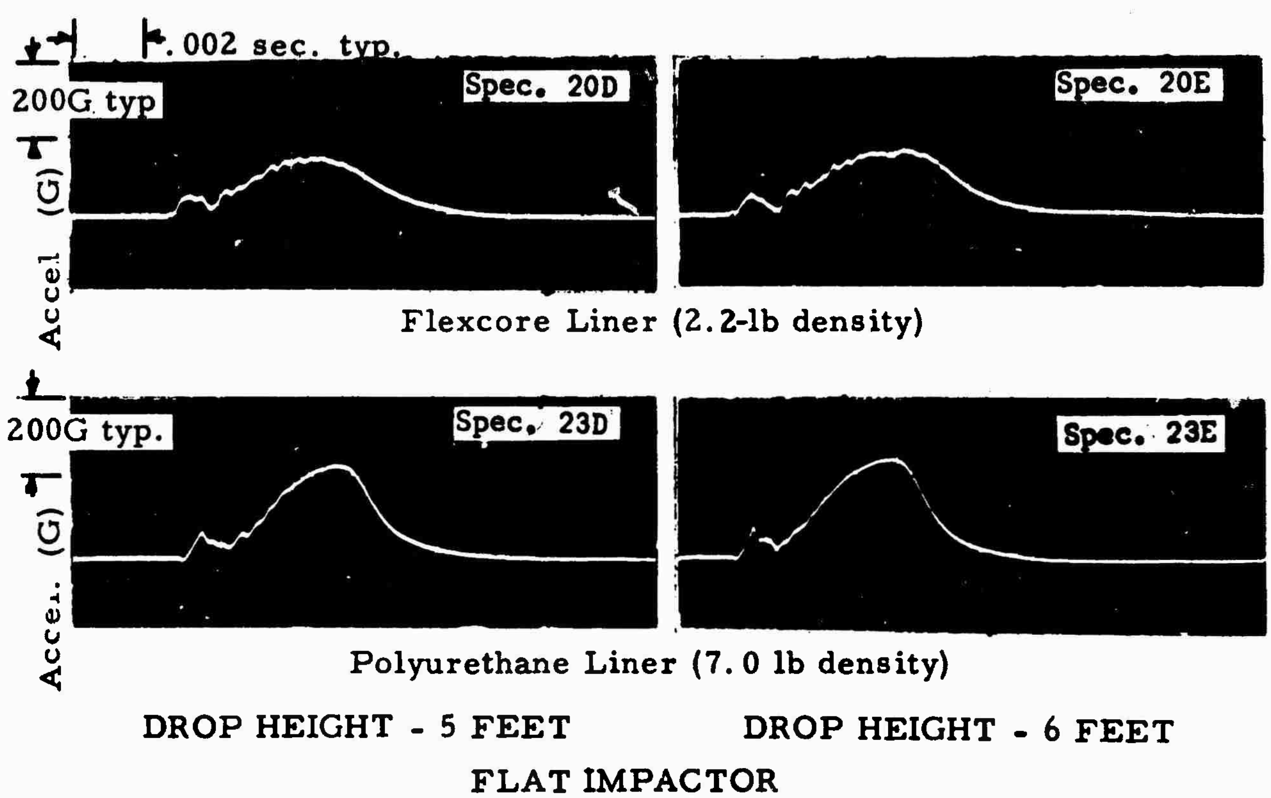


Figure 5. Acceleration-Time Data- 0.04 Annealed Aluminum 2024-0 Outer Shell.

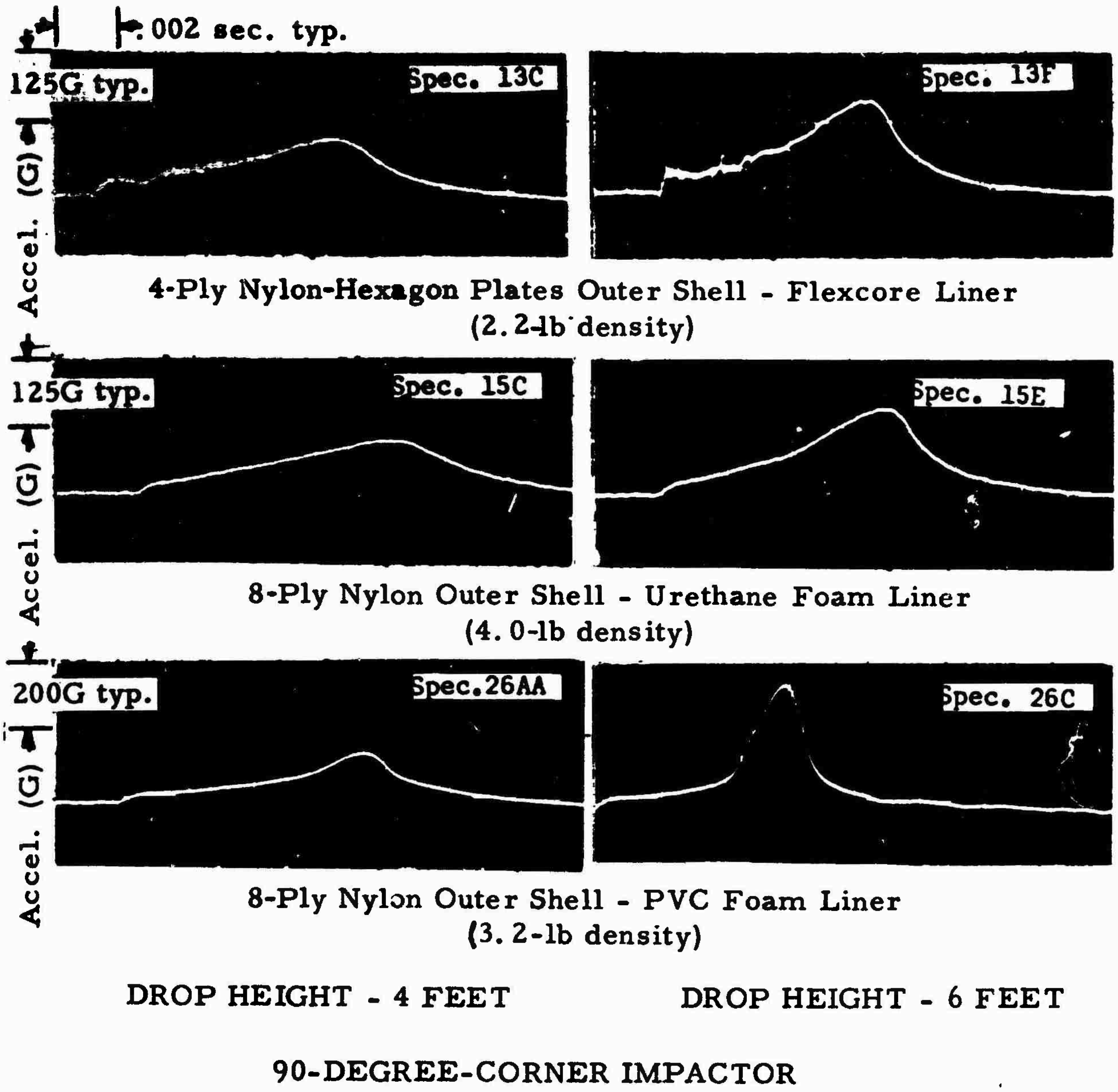
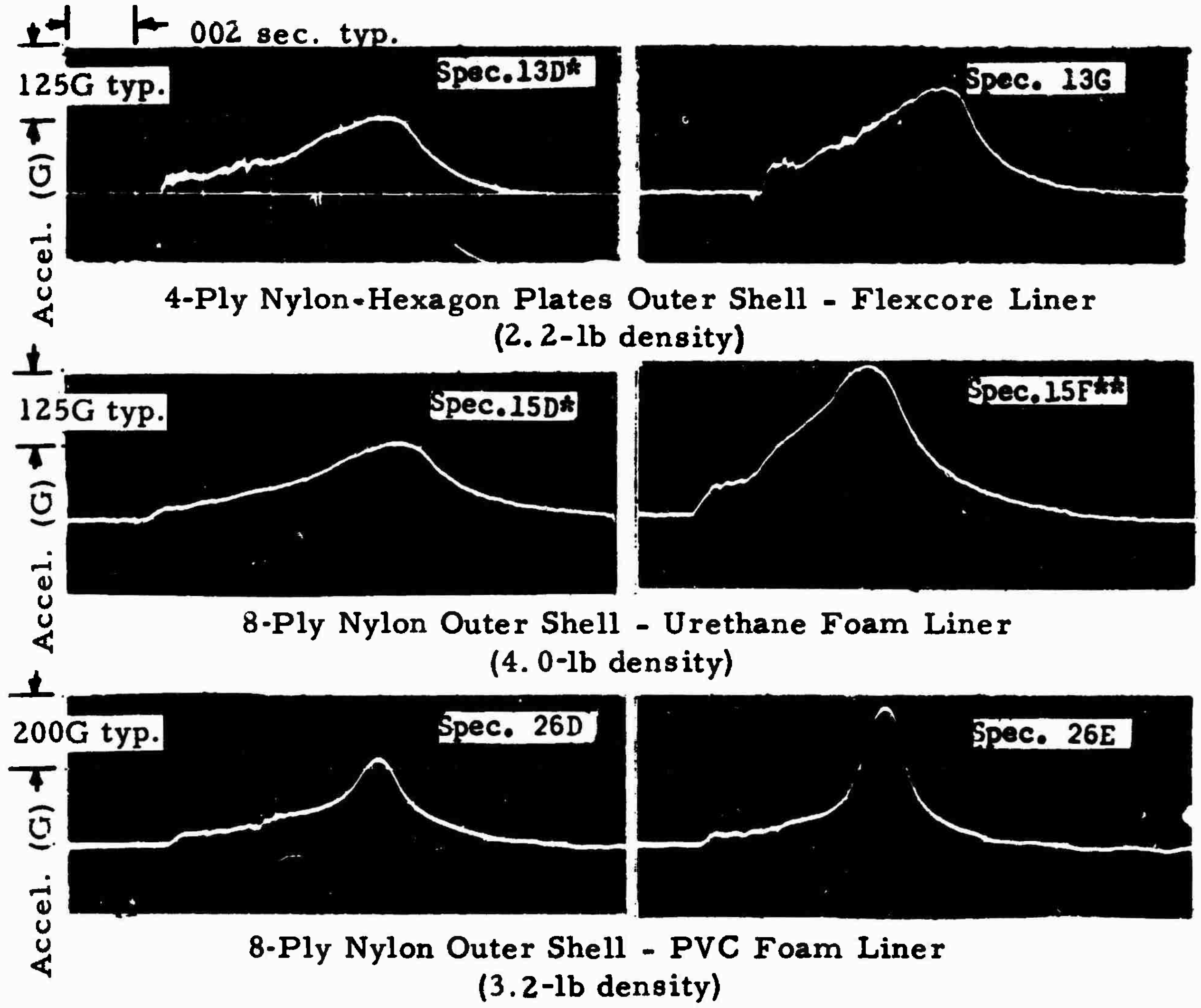


Figure 6. Acceleration-Time Data-Nylon Cloth Outer Shell.

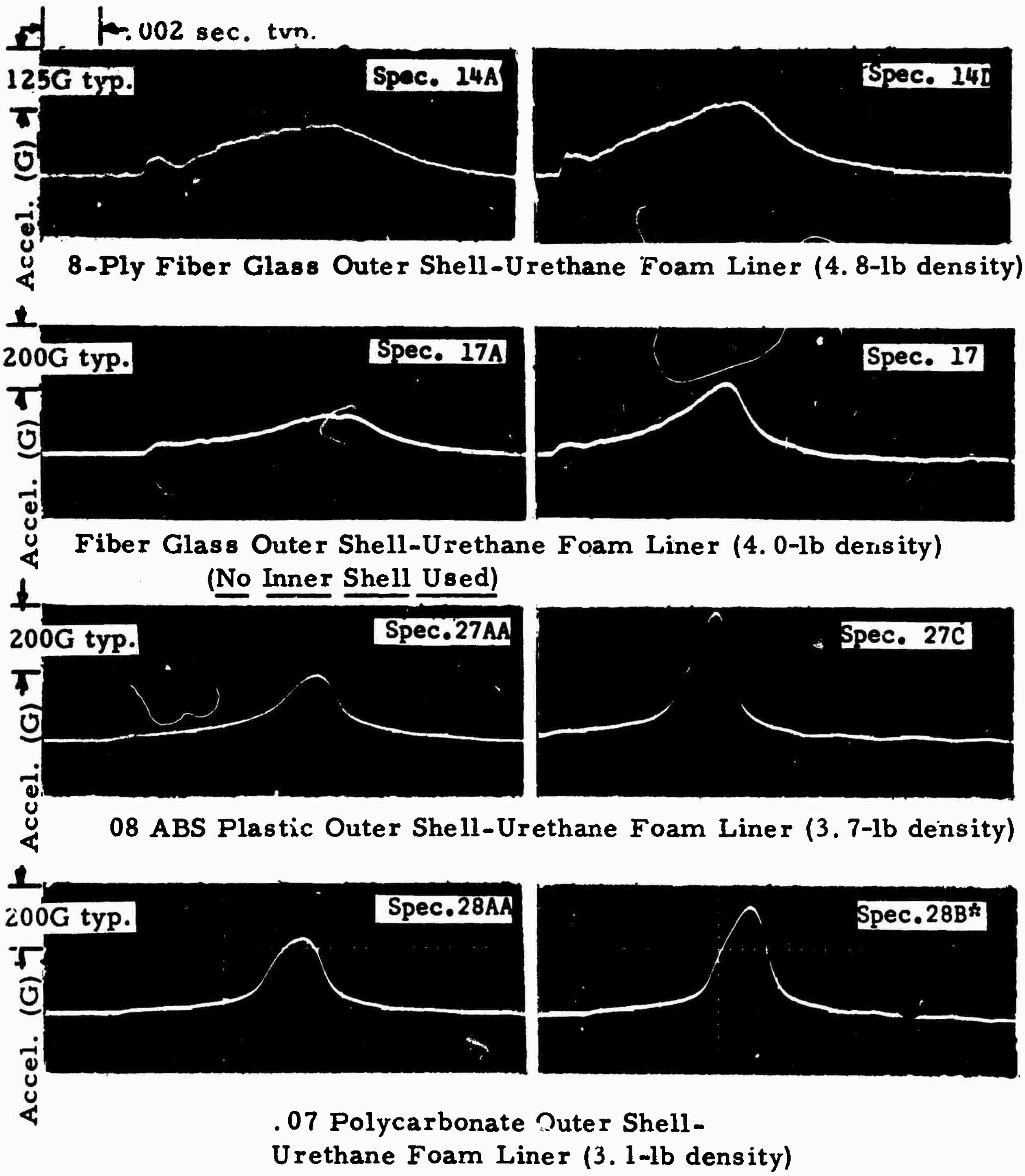


DROP HEIGHT - 5 FEET DROP HEIGHT - 6 FEET

FLAT IMPACTOR

* 90°-Corner "V" Impactor
Used Instead of Flat Impactor
** Drop Height - 10 ft. instead
of 6 ft.

Figure 7. Acceleration-Time Data-Nylon Cloth Outer Shell.

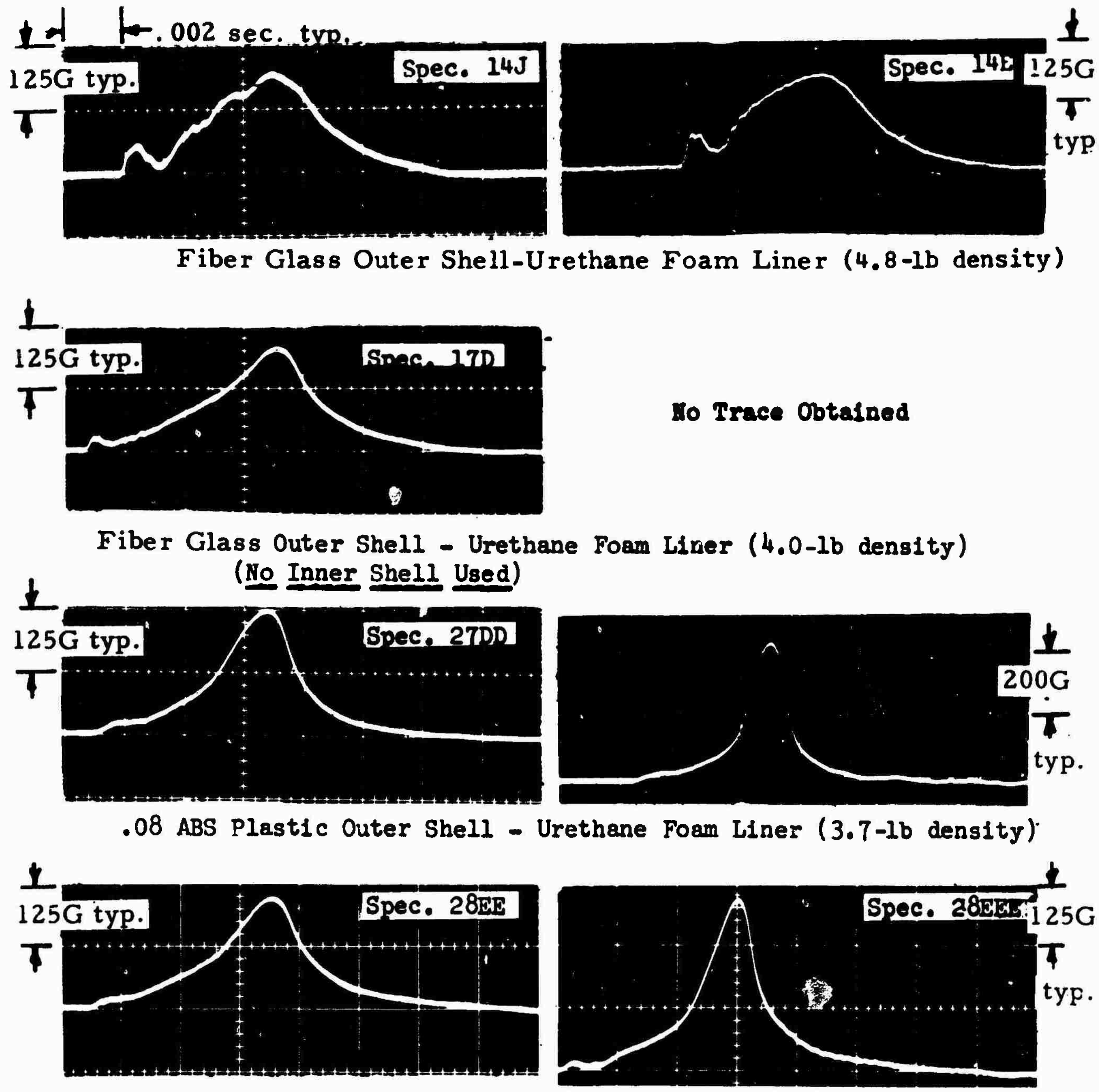


DROP HEIGHT - 4 FEET | DROP HEIGHT - 6 FEET

90-DEGREE-CORNER IMPACTOR

* 5-foot drop instead of 6-foot drop

Figure 8. Acceleration-Time Data-Fiber Glass, ABS, and Polycarbonate Outer Shells.



.07 Polycarbonate Outer Shell-
Urethane Foam Liner (3.1-lb density)

DROP HEIGHT - 5 FEET DROP HEIGHT - 6 FEET

FLAT IMPACTOR

Figure 9. Acceleration-Time Data-Fiber Glass, ABS, and Polycarbonate Outer Shells.

4. Specimen 17 (8-ply fiber glass outer shell without an inner shell), which roughly simulated the APH-5 helmet construction, can be compared with specimen 14 (8-ply fiber glass outer shell with 2-ply fiber glass inner shell). This comparison will illustrate some basic differences between the single- and double-shell concepts. The peak acceleration values for specimen 17 were greater than those of specimen 14. However, the major difference between the specimens is that permanent deformation was noted in the scalp for specimen 17 in a 4-foot drop while no deformation was noted in specimen 14. These results indicate that a low acceleration level alone may not indicate superior performance if the helmet is struck by a sharp object, because local scalp penetration may occur without a significant acceleration change.

5. The test results for specimens 18, 19, 20, 21, 22, and 23, which were constructed with 0.025 and 0.040 annealed magnesium and aluminum outer shells, indicated that the aluminum was only slightly better than the magnesium in resistance to the 90-degree cone penetration. The tests further indicated that the 0.025 shells are too thin, since a 2-foot cone drop resulted in scalp indentation, and that the 0.040 shells are acceptable for a "standard" 2-foot cone drop. Specimens 21, 22, and 23, with 6- to 7-pounds-per-cubic-foot-density urethane foams, yielded excessive acceleration levels when the flat impactor was used.

6. The test results for specimens 24, 25, and 26, which were constructed to evaluate the PVC, slow-rebound foams as primary energy absorbers, indicated excessive acceleration values for all drops. The rebound heights for these specimens in the 5-foot flat impactor drops were nearly twice the value of those recorded for the annealed metal specimens (21, 22, and 23). Thus, these material combinations do not appear to be worthy of further development.

7. Specimen 27 (0.08 ABS outer shell) permitted deformation to occur in the scalp in the standard 4-foot, 90-degree-corner drop. This specimen also resulted in rebound heights about twice those of the annealed metal shell specimens (21, 22, and 23) for the 5-foot flat impactor drops. This material combination does not appear to be worthy of further consideration.

8. Specimen 28 (0.07 polycarbonate outer shell) also permitted deformation to occur in the scalp in the standard 4-foot drop; however, the density of the liner used was only 3.1 pounds per cubic foot. Thus, the results should not be compared directly with the other specimens because a higher density foam would, no doubt, reduce

the acceleration level. The rebound height of this specimen was also nearly twice that of specimens 21, 22, and 23. The high rebound energy of this material combination appears to eliminate it from further consideration.

9. Specimens 29 and 30 were constructed with an ABS plastic outer shell, ABS foam liner, and ABS inner shell as noted in Table 1. These specimens yielded high acceleration values and rebound heights. Neither of these specimens indicates enough promise to be considered for further development.

As noted previously, uncorrected acceleration-time data are presented for some of the tested specimens in Figures 2 through 9. The 90-degree-corner impactor drops are compared at 4 feet and 6 feet, and the flat impactors at 5 feet and 6 feet. The cone drop acceleration-time curves are not presented because the resistance to penetration can be compared in Table 2, and the low acceleration values for the cone test are not critical unless complete penetration of the specimen occurs. A comparison of the acceleration values in the figures indicates that only specimens 15, 18, and 20 yield acceptable acceleration values combined with reasonably low specimen weights. Specimens 21 and 23 (0.04 magnesium and 0.04 aluminum, respectively) could be acceptable if the foam density were reduced.

The experimental helmet was constructed with the same materials used in specimen 21 with the exception that the foam density was reduced to the range of 3 to 5 pounds per cubic foot.